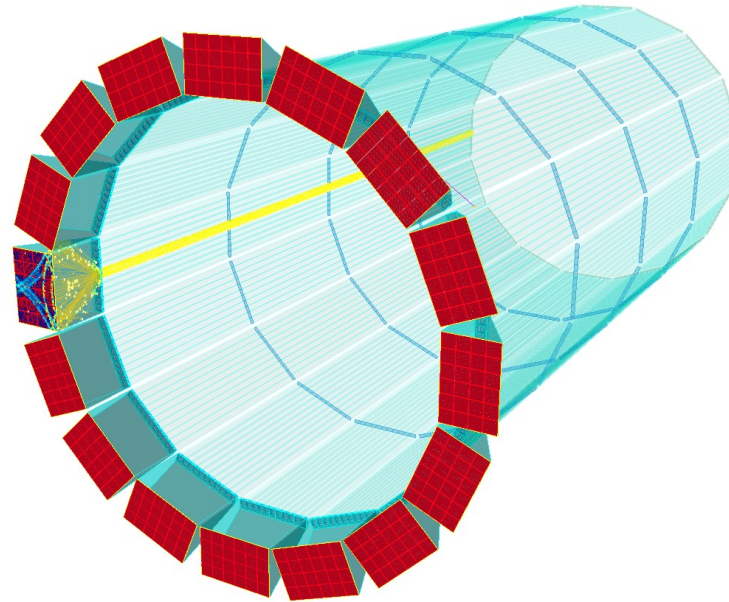


# THE HIGH-PERFORMANCE DIRC FOR THE EIC

Progress and Future R&D Priorities



Jochen Schwiening



GSI Helmholtzzentrum für Schwerionenforschung GmbH

Detector R&D Advisory Committee Meeting, March 24, 2021

eRD14 hpDIRC Group

R. Dzhygadlo, Y. Ilieva, T. Hartlove, C. Hyde, G. Kalicy, A. Lehmann, P. Nadel-Turonski,  
M. Patsyuk, K. Peters, C. Schwarz, J. Schwiening, N. Wickramaarachchi, C. Zorn



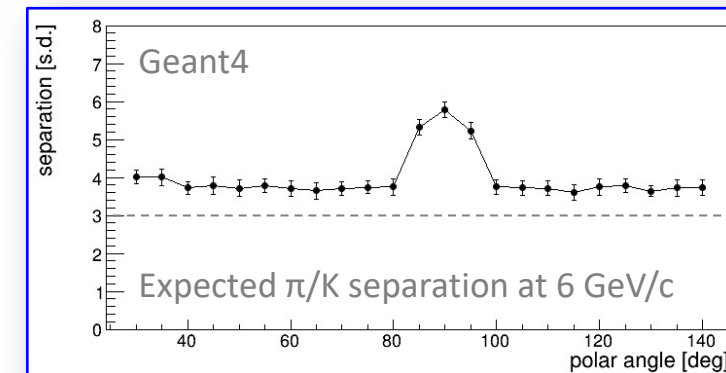
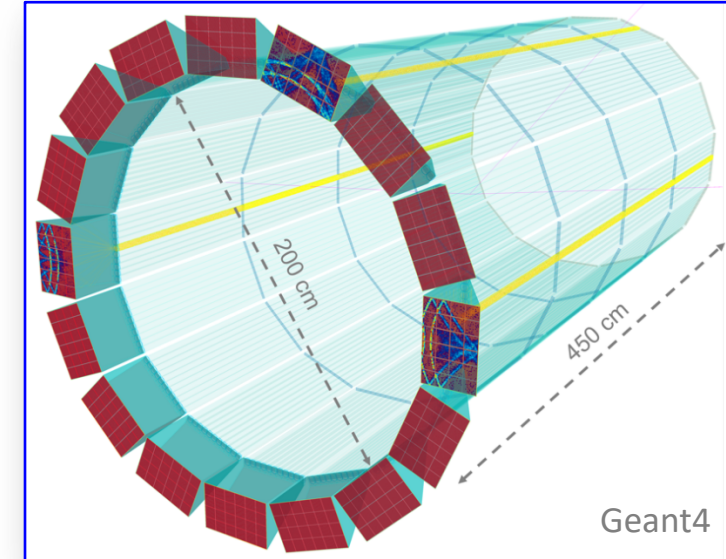
# HPDIRC ACTIVITY OVERVIEW

## High-Performance DIRC Goal:

- To develop a **very compact barrel EIC PID** detector with momentum coverage reaching **6 GeV/c for  $\pi/K$** , pushing the performance well beyond the state-of-the-art for DIRC counters.

## Concept:

- **Fast focusing DIRC**, utilizing **high-resolution 3D (x,y,t) reconstruction**
- Initial generic design (based on BaBar DIRC, R&D for SuperB FDIRC, PANDA Barrel DIRC): narrow fused silica bars, 1m barrel radius, 4.5m barrel length  
(*barrel length and radius to be optimized for detector integration - no impact on DIRC PID*)
- **Innovative 3-layer spherical lenses**, compact fused silica expansion volumes
- **Fast photon detection** using small-pixel MCP-PMTs (*eRD14*) and high-density readout electronics (*eRD14*)
- Detailed Geant4 simulation:  
40-120 detected photons per particle,  **$\geq 3$  s.d.  $\pi/K$  separation at 6 GeV/c**



# HPDIRC R&D PRIORITIES

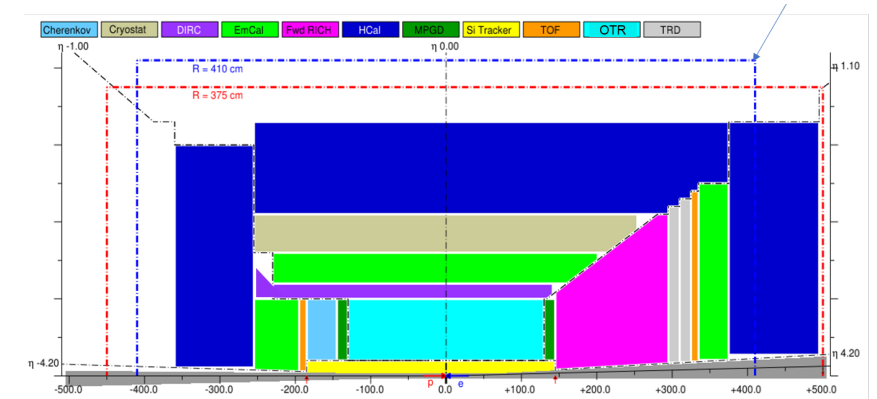
EIC Yellow Report: hpDIRC is the baseline hadronic PID system for the EIC detector barrel (combined with dE/dx at low momentum)

- First alternative: hpDIRC with reused BaBar DIRC bars
- EIC project issued call for EIC detector collaboration proposals (3/2021)
- Detector proposals at recent workshops, including EIC@IP6 and CORE, feature the hpDIRC with layout solutions for DIRC prism integration
- Demanding project schedule: CD-2 (1/2023), CD-3 (3/2024)

## R&D Priorities: Minimize risks, realize opportunities

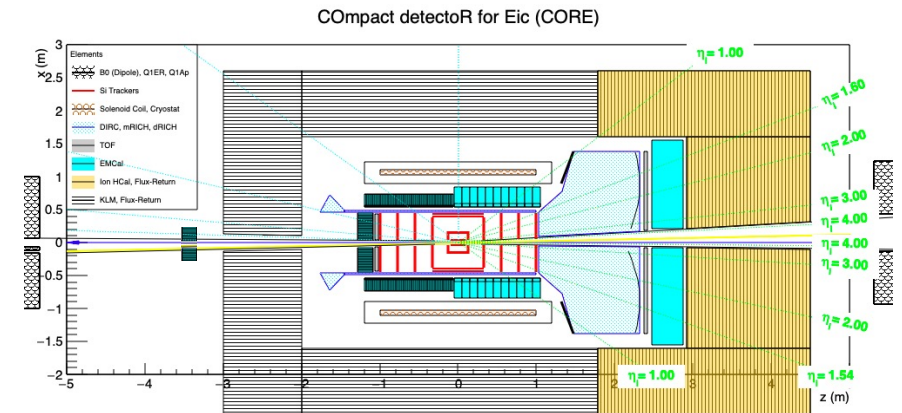
- Technical risk: hpDIRC PID design validation
- Technical risk: photon sensor performance in 3 Tesla magnet
- Technical risk/opportunity: reuse of BaBar DIRC bars
- Opportunity: improve  $e/\pi$  separation at low momentum, further push  $\pi/K$  performance at high momentum

### hpDIRC in YR reference detector



Y. Furletova, IR2@EIC workshop, March 17, 2021

### hpDIRC in CORE proposal



P. Nadel-Turonski, IR2@EIC workshop, March 17, 2021

## Technical risk: hpDIRC PID design validation

- Radiation hardness and focusing performance of 3-layer lens

Conventional plano-convex lens with **air gap** limits DIRC performance

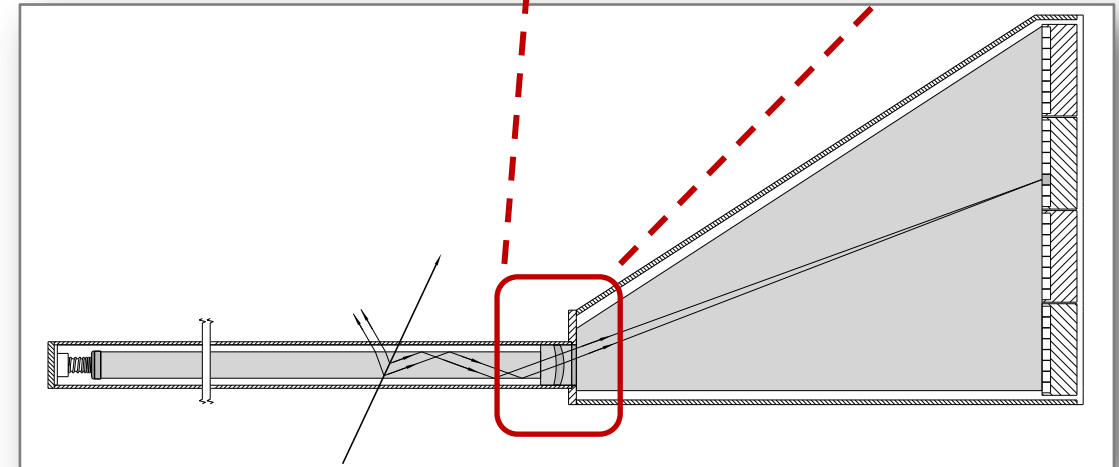
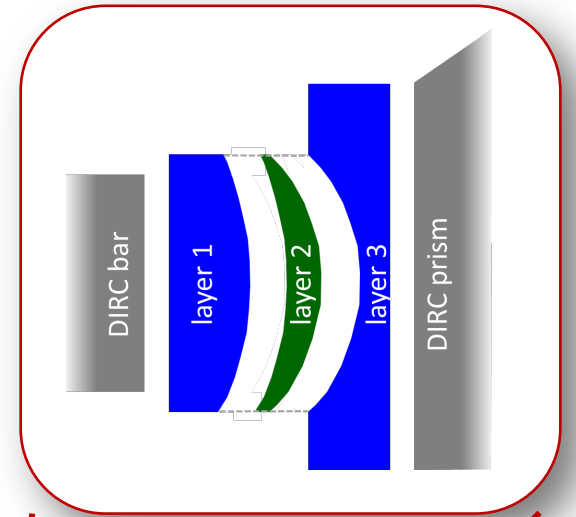
- Significant **photon yield loss** for particle polar angles around  $90^\circ$ , gap in DIRC PID
- **Distortion of image plane**, PID performance deterioration

Key element of hpDIRC design:

- 3-layer compound lens (without air gap):

layer of **high-refractive index material** (focusing/defocusing)  
sandwiched between **two layers of fused silica**

- Creates flat focal plane – matched to fused silica prism shape
- Avoids photon loss and barrel PID gap
- Successfully produced prototype lenses and validated performance in PANDA Barrel DIRC prototype with particle beams at CERN and GSI



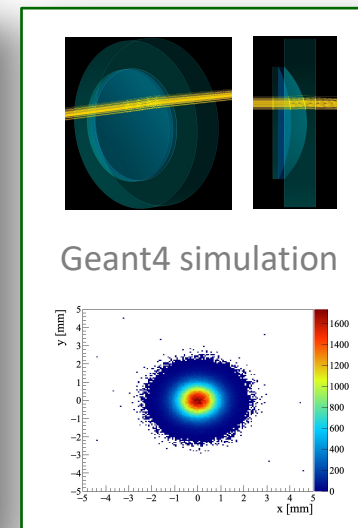
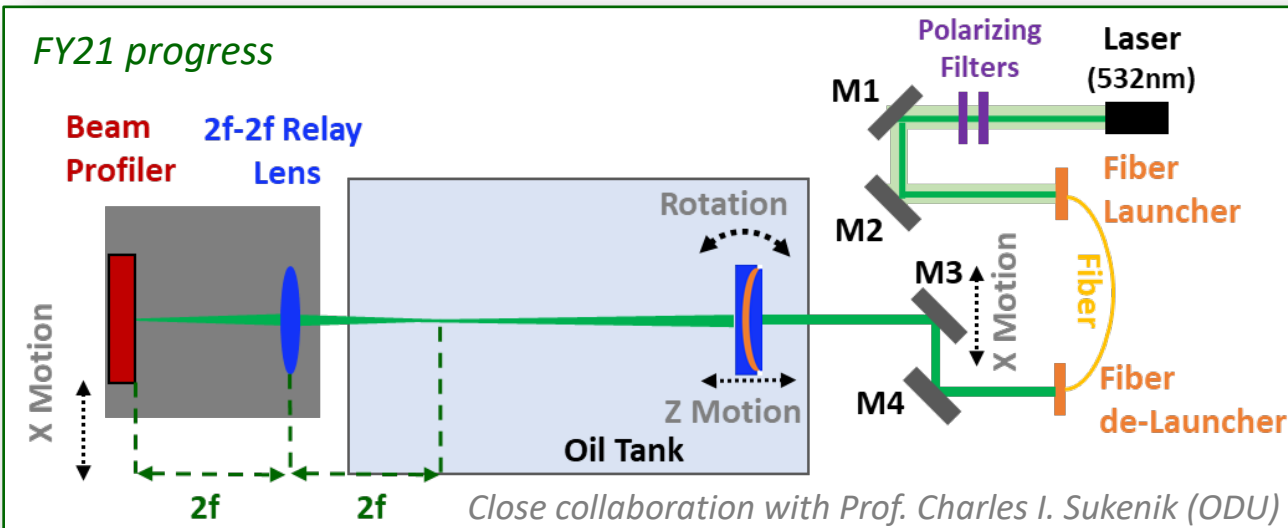
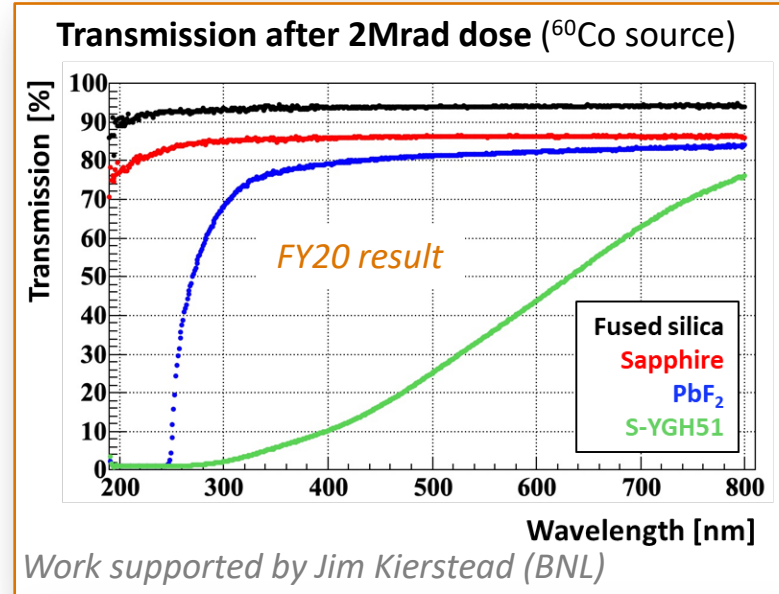
# HPDIRC R&D PRIORITIES / FY21 HIGHLIGHTS

## Technical risk: hpDIRC PID design validation

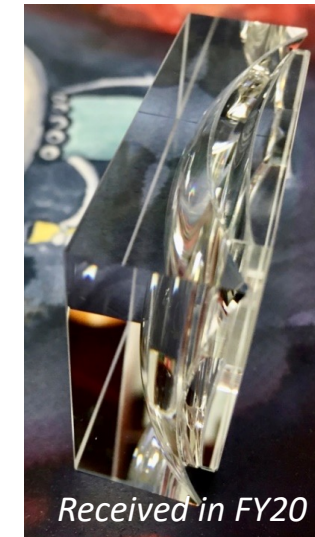
- Radiation hardness and focusing performance of 3-layer lens

### hpDIRC R&D activities:

- Identify radiation-hard material for middle layer ( $^{60}\text{Co}$  study complete, neutrons next)
- Demonstrate that rad-hard material is suitable for lens fabrication by industry (New sapphire and  $\text{PbF}_2$  lens prototypes produced, ready for tests)
- Validate focusing properties/flat focal plane
  - completed upgrade of laser setup at ODU in FY21, starting lens scans



Sapphire (RMI, USA)



$\text{PbF}_2$  (HIT, China)



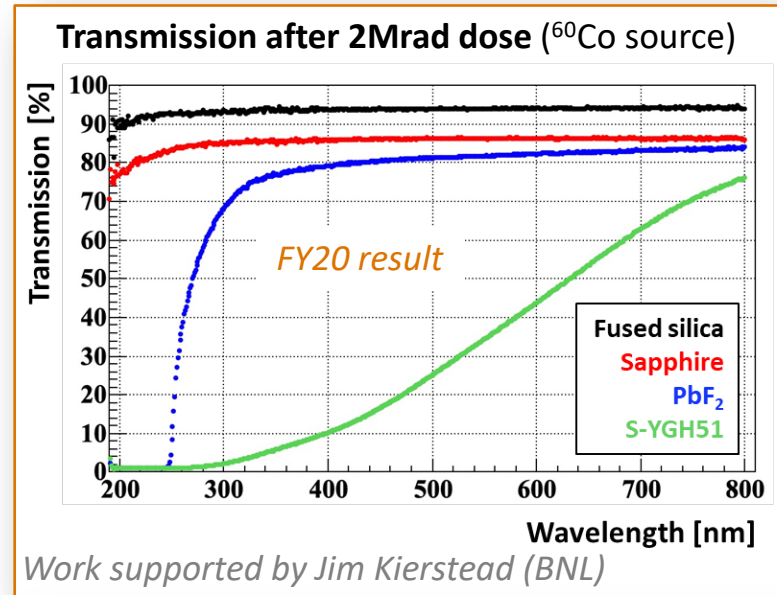
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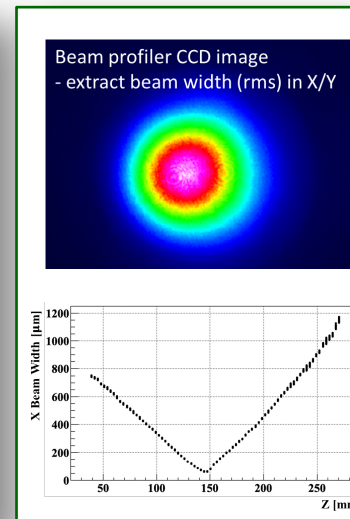
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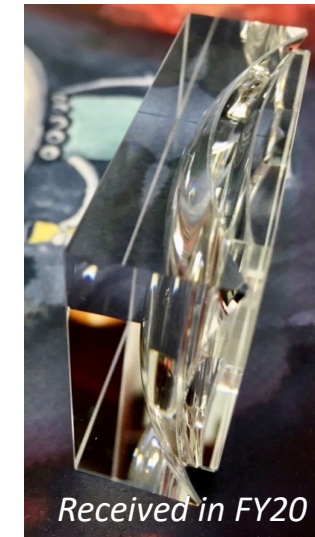
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  - completed upgrade of laser setup at ODU in FY21, starting lens scans



### FY21 progress



### Sapphire (RMI, USA)



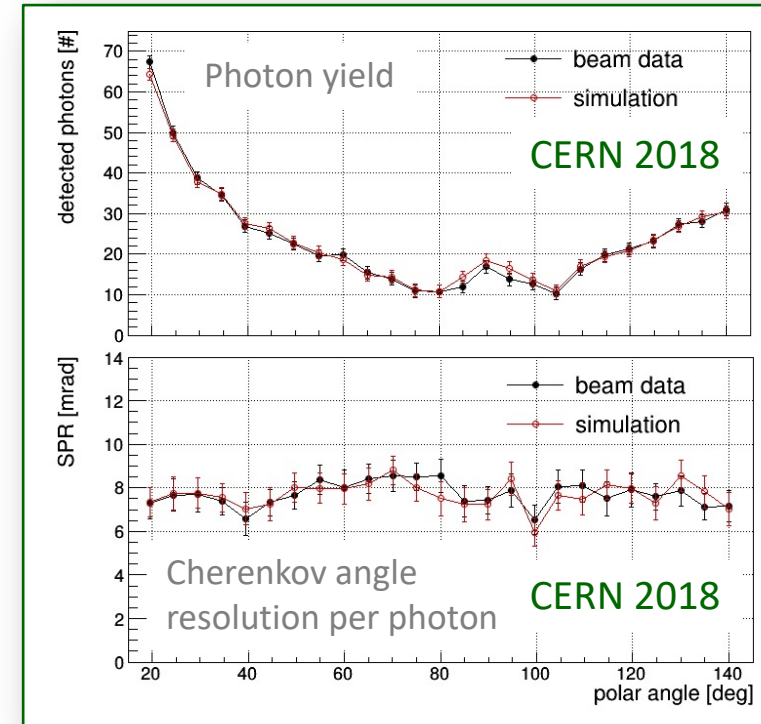
### $\text{PbF}_2$ (HIT, China)



# HPDIRC R&D PRIORITIES

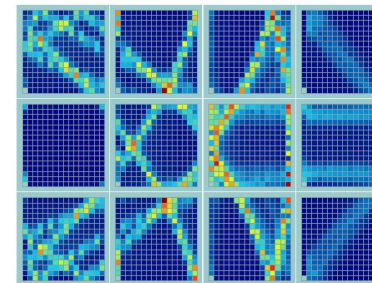
## Technical risk: hpDIRC PID design validation

- Resolution and PID performance of system prototype
- PANDA Barrel DIRC prototype tested with particle beams at CERN (2015-18)  
(included 3-layer spherical lens – but older MCP-PMTs, larger pixels, slower electronics)
- Recently optimized event selection and analysis procedure for CERN 2018 data  
(in preparation for upcoming journal publication)
- Up to 5 s.d.  $p/\pi$  separation at 7 GeV/c (equivalent to 5.2 s.d.  $\pi/K$  at 3.5 GeV/c)
- Excellent agreement with simulation (same simulation used for hpDIRC)
- Used this simulation to predict PID performance of upgraded prototype  
(new MCP-PMTs and electronics, 3mm pixels, improved PDE, 100ps timing)
- Expected  $\pi/K$  separation at 6 GeV/c at 20°: 3.1 s.d.
- Upgraded PANDA Barrel DIRC prototype (new sensors, new electronics)  
capable of hpDIRC PID performance validation in particle beams

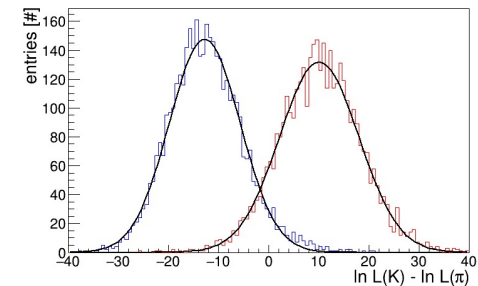


## Geant simulation of upgraded prototype

Accumulated hit pattern



$\pi/K$  separation at 6 GeV/c at 20°



# HPDIRC R&D PRIORITIES / FY21 HIGHLIGHTS

## Preparation of Tests of DIRC Prototype with Cosmic Rays

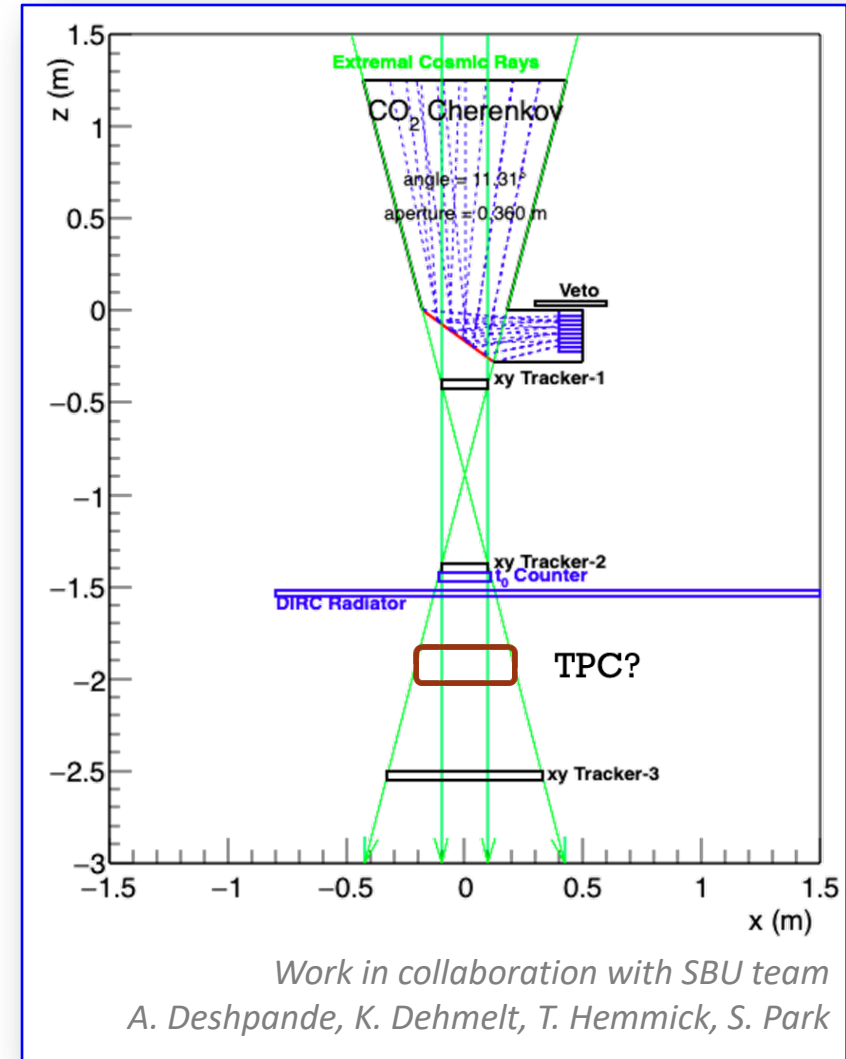
- Crowded beam test schedules – validate hpDIRC with cosmic muons
- Started bi-weekly meetings (CUA – GSI – ODU – SBU) to develop cosmic ray telescope (CRT) design and measurement plan

### Current design:

- Momentum selection: new CO<sub>2</sub> Cherenkov threshold tagger ( $> \sim 3.5$  GeV/c)
- 3D tracking: two GEM tracker stations (from sPHENIX) above and below DIRC bar, potentially combined with TPC prototype
- Shower rejection: scintillator plates as veto counters
- T<sub>0</sub> start counter: LAPPD or mRPC prototype or commercial MCP-PMT
- Mechanical design progressing, prototype polar angle rotation foreseen
- Geant simulation package in preparation

Plan to start measurements in late summer (prototype transfer to US still delayed)

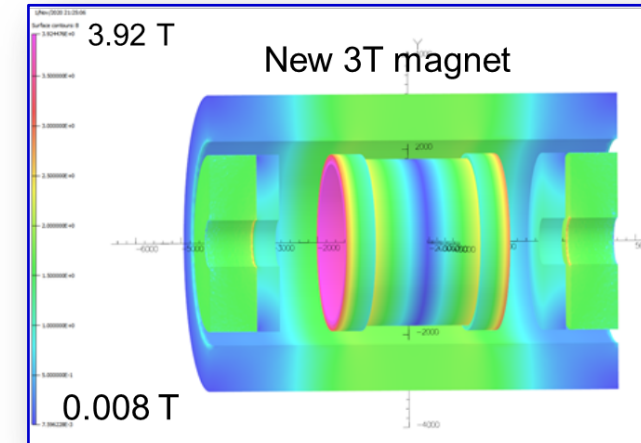
Prototype upgrade will require significantly increased funding for new MCP-PMT sensors (commercial / LAPPD) and readout electronics, continued cooperation with electronics experts (eRD14 and external)



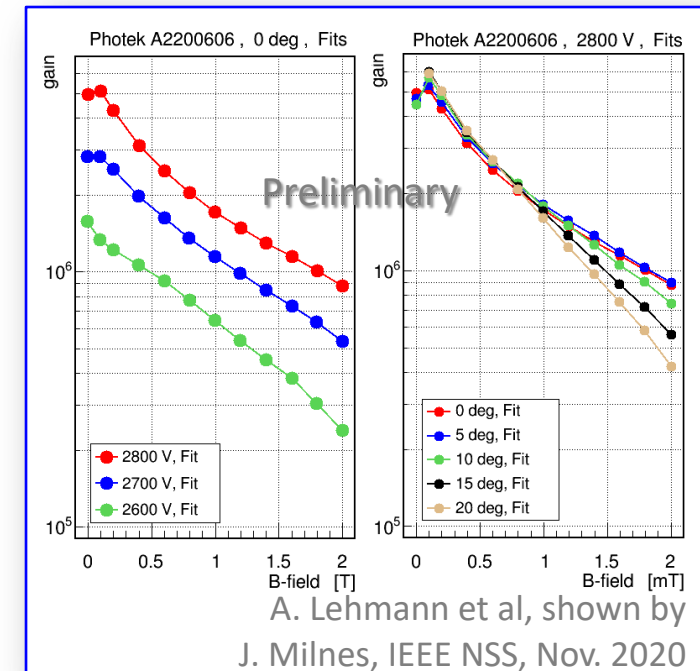
# HPDIRC R&D PRIORITIES

## Technical risk: photon sensor performance in 3 Tesla magnet

- Some of the detector proposals plan to use a new 3 T magnet, other proposals favor magnets with 1.5—2 Tesla fields
- Waiting for field maps for proposed new 3 Tesla magnet (EIC@IP6) to determine **local field strength and direction** at location of DIRC sensors
- Ongoing effort within eRD14, studying LAPPD/commercial MCP-PMT in high B-fields
- **Small-pore MCP-PMTs shown to be OK for fields up to 2 Tesla** (see recent result from A. Lehmann et al. for 6 $\mu$ m-pore 2" Photek AuraTek MCP-PMT)
- If expected fields are much higher: **investigate SiPM as alternative** (dark noise, radiation damage, cooling, annealing, integration issues)



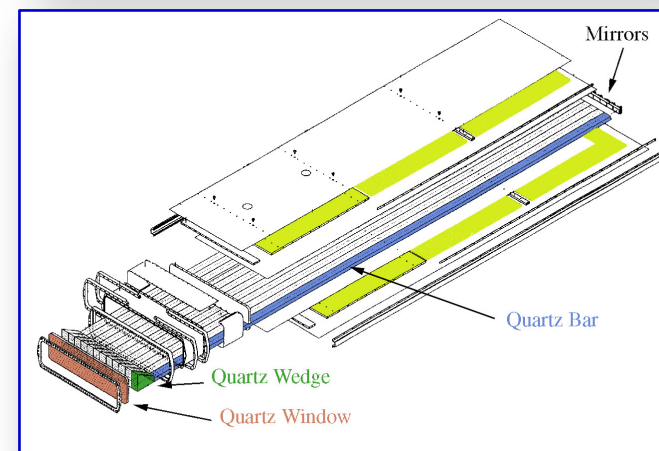
Y. Furletova, IR2@EIC workshop, March 2021



# HPDIRC R&D PRIORITIES

## Technical risk/financial opportunity: reuse of BaBar DIRC bars

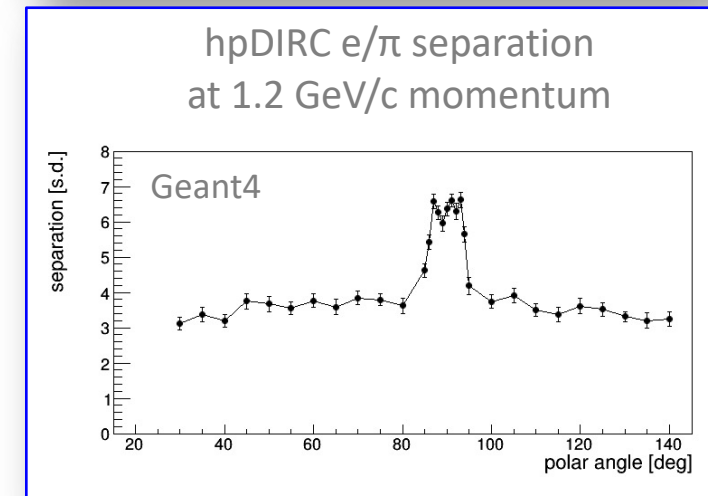
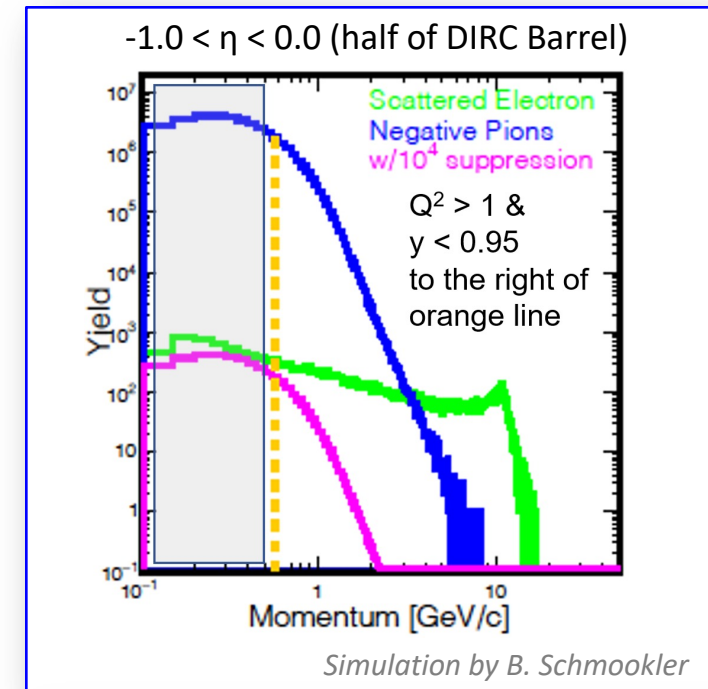
- BaBar DIRC disassembled in 2010, SLAC/DOE made DIRC bars available for reuse
- Save cost, reduce technical and schedule risk related to fabrication of new bars
- Eight bar boxes still available at SLAC, awarded to JLab for potential use in EIC  
Four unmodified bar boxes at JLab for GlueX DIRC since 2018 (may be available for EIC)
- Full-size bar boxes are too long, do not fit into EIC central detector, wedges deteriorate resolution: need to disassemble bar boxes for reuse
- Twelve bar boxes: 576 bars (each  $17 \times 35 \times 1200 \text{ mm}^3$ ), sufficient number for EIC (even 8 bar boxes may be enough if bars can be extracted with good quality and excellent yield)
- In contact with SLAC BaBar experts, discussed concept for disassembly of bar box and decoupling of bars from wedge and other bars using heat gun approach
- R&D will be required to develop procedure and to assess cost and technical risk (Optical quality? Yield? DIRC clean room at SLAC? Funding (tooling, SLAC labor, travel)? Is additional cutting/polishing required to refinish ends and/or reduce bar length?)



# HPDIRC R&D PRIORITIES

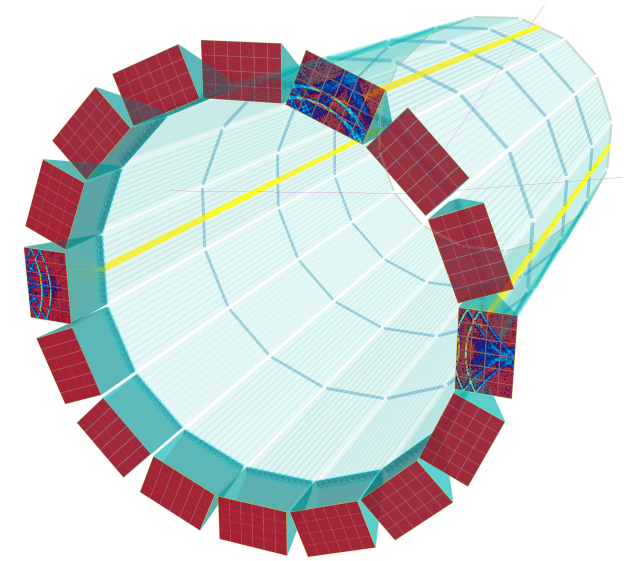
## Performance opportunity: improve $e/\pi$ separation at low momentum

- Yellow report effort identified need for **supplemental  $e/\pi$  suppression** from PID systems to support EM calorimeter at lower momentum
- Simulation shows that ID of scattered electron requires  $O(10^4)$  suppression of large pionic background
- Started simulation effort, multiple scattering limits hpDIRC performance
- Recent result, without special measures: **> 3 s.d.  $e/\pi$  separation at 1.2 GeV/c** (caveat: long non-Gaussian tails)
- Even “out-of-the-box” hpDIRC capable of very useful background suppression
- Better performance possible, study use of **post-DIRC tracking**, “**ring center fit**”, **optimized DIRC geometry** (bar width/thickness, bar/plate hybrid), etc.
- Post-DIRC tracking expected to further **improve  $\pi/K$  separation at high momentum**



## Progress and Future R&D Priorities:

- Progress on **high-priority future R&D topics** towards hpDIRC in “Detector 1/IP6” and “Detector 2/IP8”
- Goals: **Minimize risks, realize opportunities**
- **Validation of 3-layer spherical lens:** nearing completion in FY21
  - Upgrade of setup at ODU complete, lens scans starting
  - Ready for neutron irradiation at UMass Lowell this summer
- **Cosmic ray telescope:** setup at SBU in preparation, design advancing, system prototype tests to start this fall, Geant simulation in preparation
- **Simulation projects:** study of  $e/\pi$  separation and bar geometry underway, study of “ultimate DIRC” and hpDIRC implementation into detector frameworks soon



**Thank you for your attention**



# EXTRA MATERIAL

## Technical risk: hpDIRC PID design validation

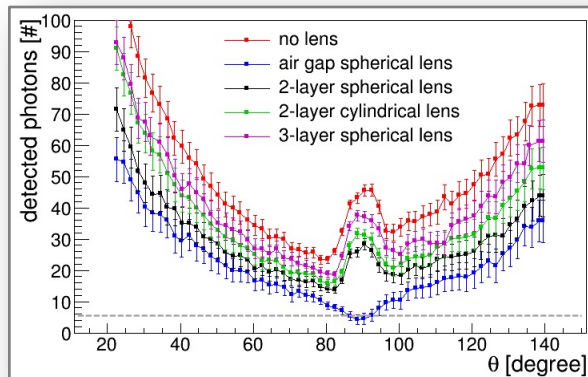
- Radiation hardness and focusing performance of 3-layer lens

Conventional plano-convex lens with **air gap** limits DIRC performance

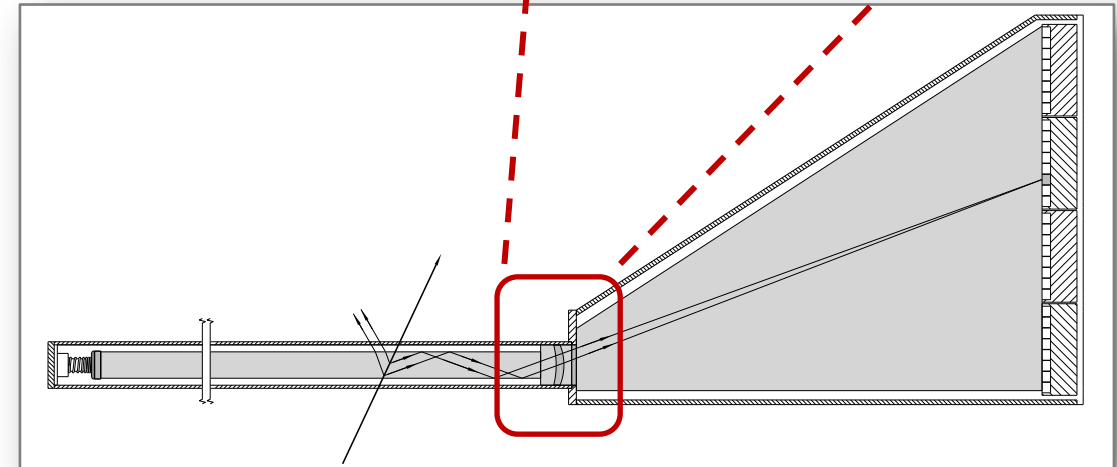
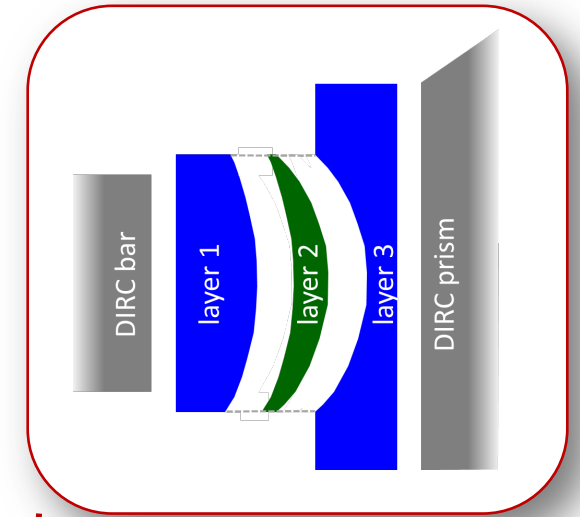
- Significant **photon yield loss** for particle polar angles around 90°
- **Distortion of image plane** for photons with steeper propagation angles

Key element of hpDIRC design:

- 3-layer compound lens (without air gap):  
layer of **high-refractive index material** (focusing/defocusing)  
sandwiched between **two layers of fused silica**



Source:  
PANDA Barrel DIRC TDR



# HPDIRC R&D PRIORITIES / FY21 HIGHLIGHTS

## Technical risk: hpDIRC PID design validation

- Radiation hardness and focusing performance of 3-layer lens

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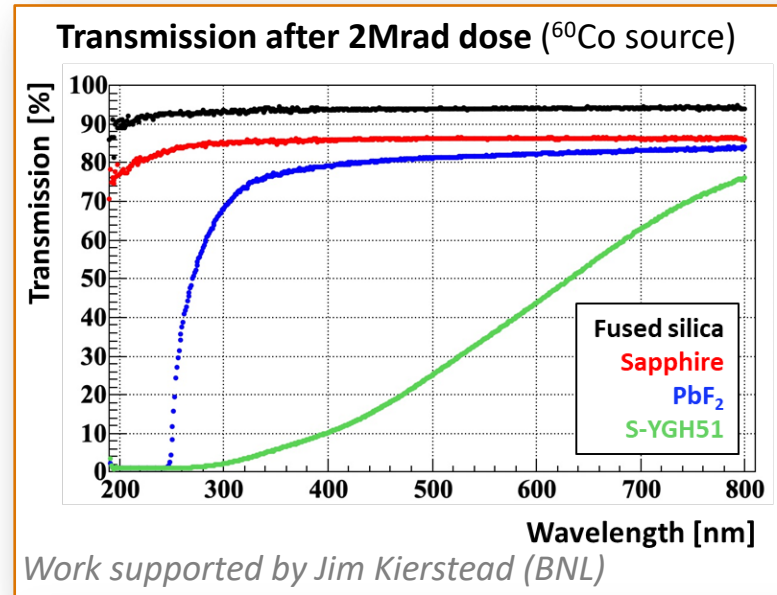
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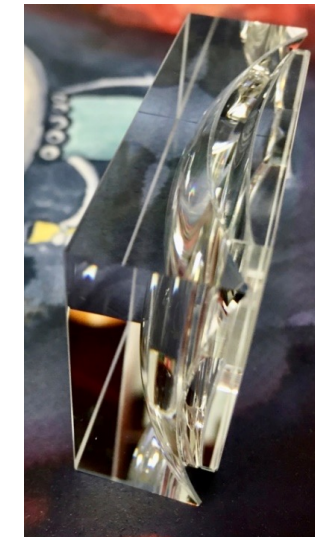
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## hpDIRC R&D activities:

- Identify radiation hard material for middle layer (<sup>60</sup>Co completed, neutrons next)
- Demonstrate that rad-hard material is suitable for lens fabrication by industry (prototype lenses produced, ready for tests)
- Validate focusing properties/flat focal plane → upgraded laser setup at ODU



Sapphire (RMI, USA)



PbF<sub>2</sub> (HIT, China)

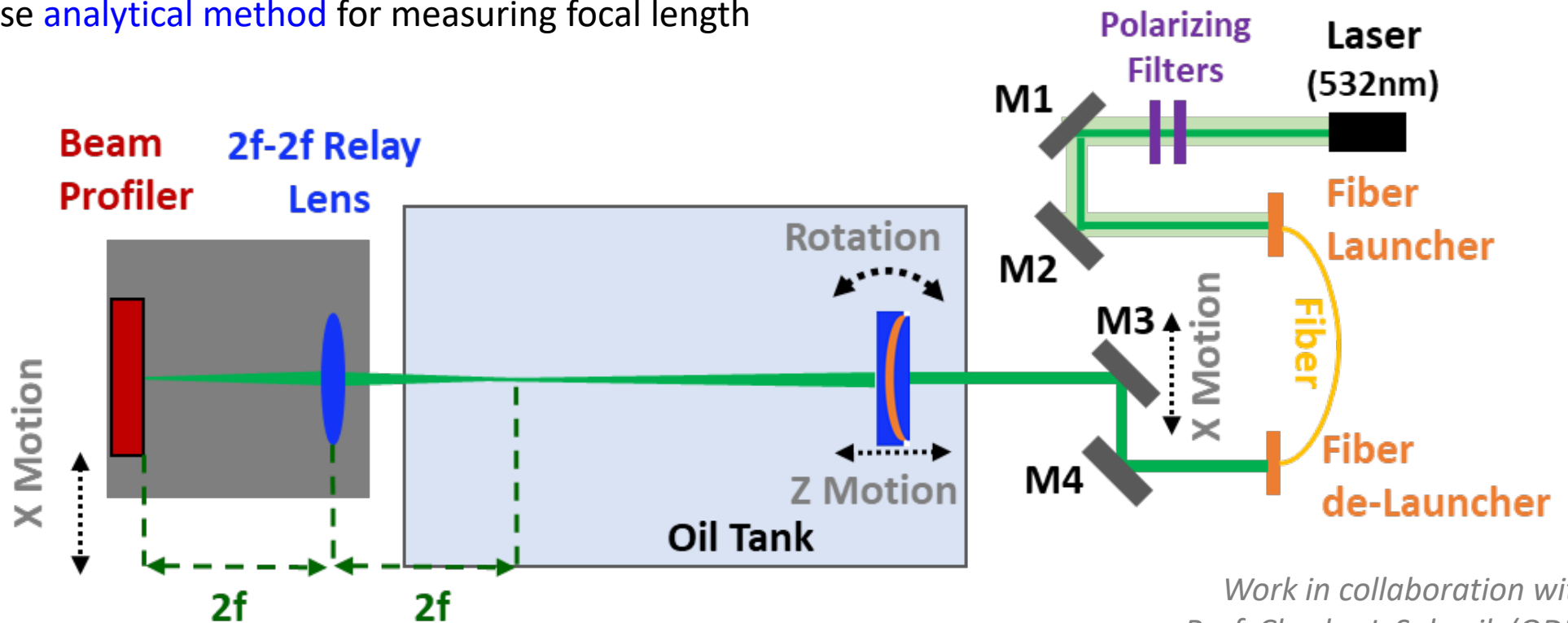
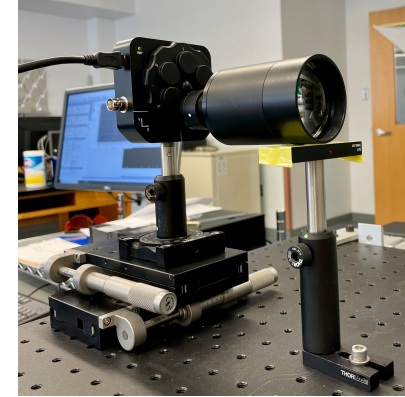


Received in FY21

# HPDIRC R&D PRIORITIES / FY21 HIGHLIGHTS

## Upgrade of laser setup at ODU

- Setup for evaluation of the **shape of the focal plane** of prototype lenses
- Completed upgrade: heavier mechanical support, laser fiber launcher, 2f-2f relay lens, CCD camera beam profiler with commercial software
- Better **quality of laser beam**, more **repeatable positioning**, faster and more precise **analytical method** for measuring focal length

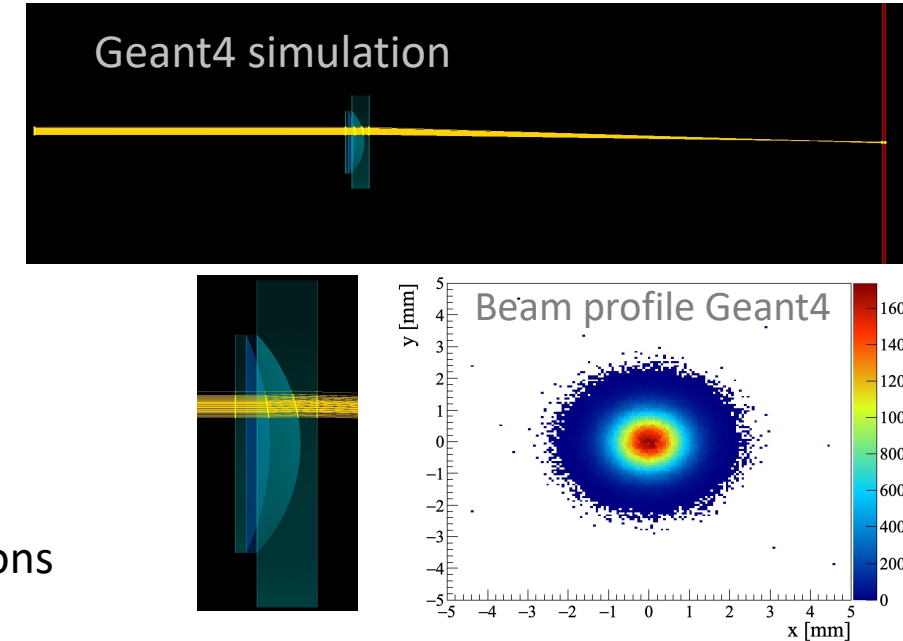


Work in collaboration with  
Prof. Charles I. Sukenik (ODU)

# HPDIRC R&D PRIORITIES / FY21 HIGHLIGHTS

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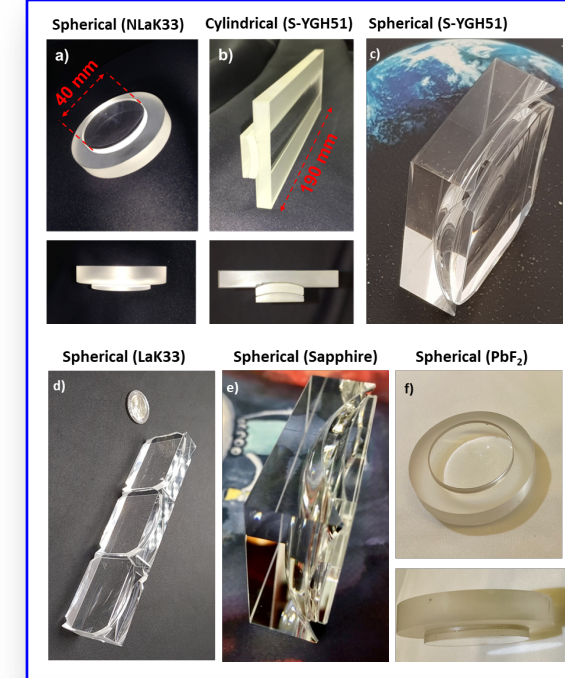
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- Developed **Geant simulation of setup** – improve understanding of aberrations



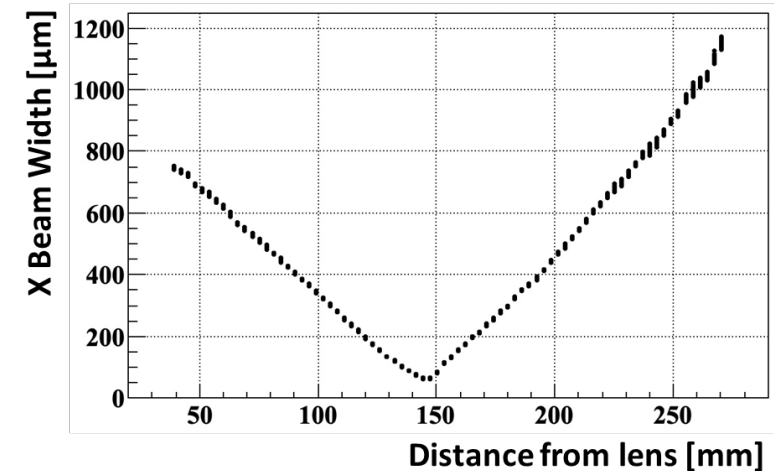
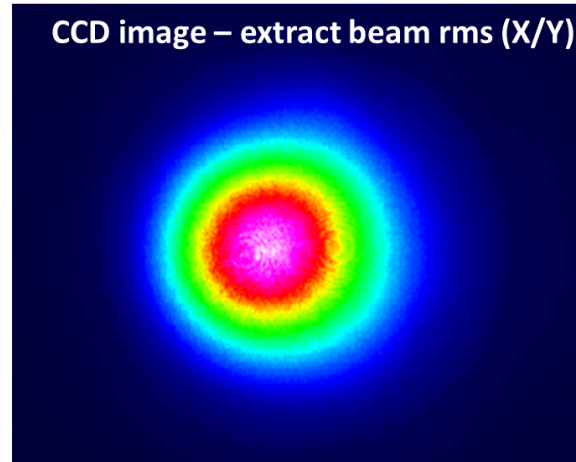
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- Better **quality of laser beam**, more **repeatable positioning**, faster and more precise **analytical method** for measuring focal length
- Developed **Geant simulation of setup** – improve understanding of aberrations
- Calibration complete, lens scans started
- Several compound lens prototypes available

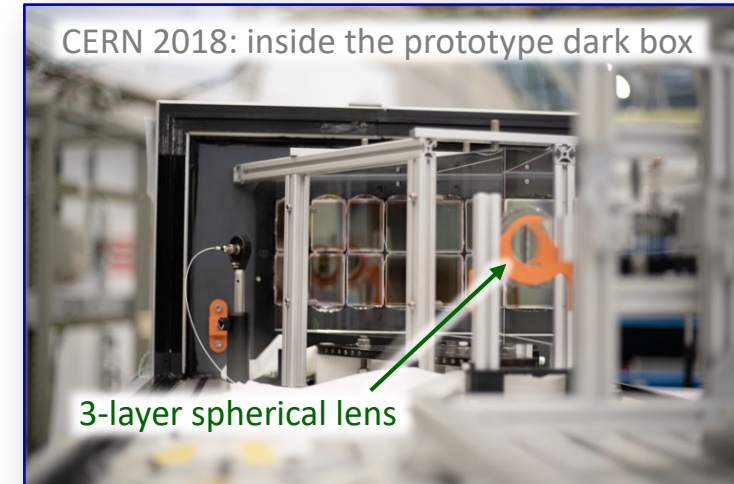


CCD image – extract beam rms (X/Y)



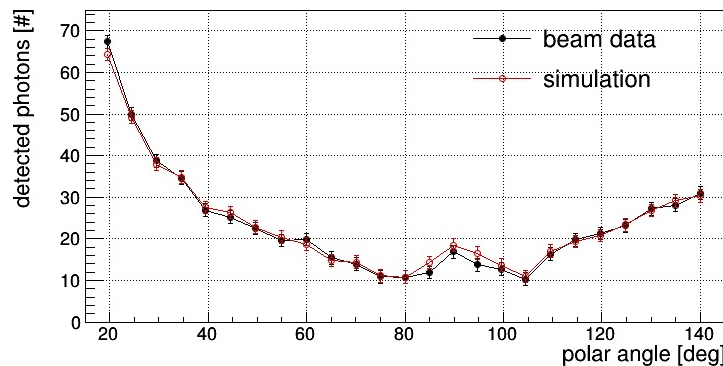
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- Recently optimized event selection and analysis procedure for CERN 2018 data (in preparation for upcoming journal publication)
- Achieved 5 s.d.  $p/\pi$  separation at 7 GeV/c, excellent agreement with simulation

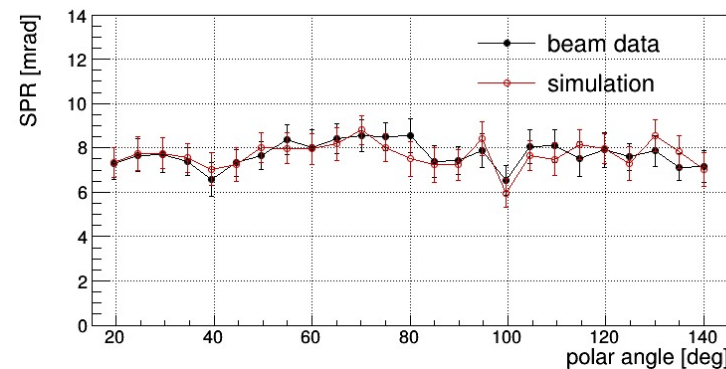


## CERN 2018

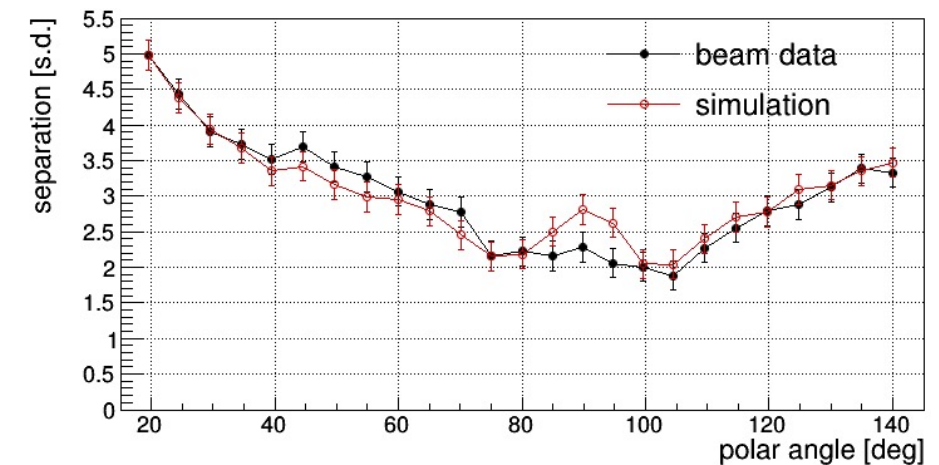
Photon yield



Cherenkov angle resolution per photon



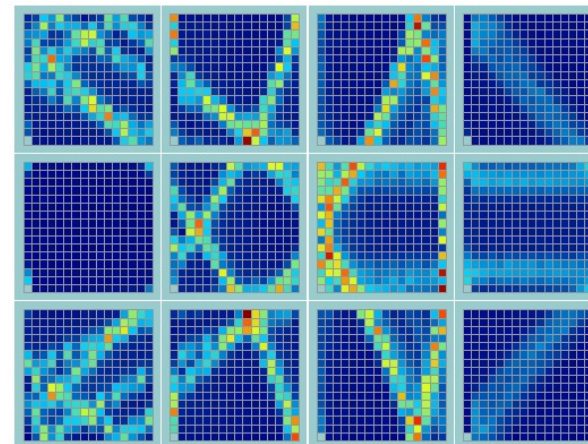
$p/\pi$  separation power at 7 GeV/c



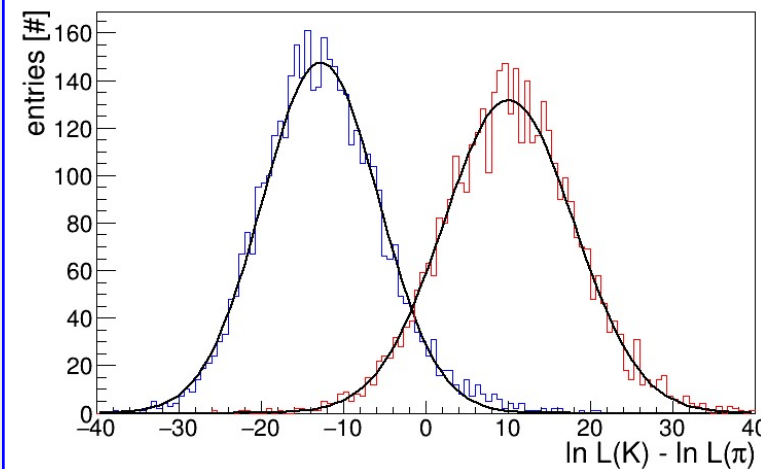
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(in preparation for upcoming journal publication)
- Achieved 5 s.d.  $p/\pi$  separation at 7 GeV/c, excellent agreement with simulation
- Used this simulation to predict performance for upgraded prototype
  - Assumed replacement of older Planacon MCP-PMTs with current commercial MCP-PMTs ( $3 \times 3 \text{ mm}^2$  pixels, improved PDE)
  - Assumed improved single photon timing (100ps rms)
- Predicted  $\pi/K$  separation at 6 GeV/c at  $20^\circ$ : 3.1 s.d.
- Upgraded PANDA Barrel DIRC prototype (new sensors, new electronics)  
capable of hpDIRC PID performance validation in particle beams

Accumulated hit pattern  
for upgraded prototype (Geant4)



$\pi/K$  separation at 6 GeV/c at  $20^\circ$ : 3.1 s.d.  
for upgraded prototype (Geant4)





# FY21 BUDGET REQUEST

# HPDIRC SUMMARY AND BUDGET REQUEST

## FY 21 Plan:

- Nilanga, new **PostDoc** responsible for simulation and prototyping, started June 1<sup>st</sup>  $\Rightarrow$  **budget request** to extend contract
- Incremental **upgrade of prototype** with small-pixel commercial MCP-PMTs  $\Rightarrow$  **budget request** for two new sensors
- Complete **transfer of prototype**, evaluate performance at SBU  $\Rightarrow$  **budget request** for travel (CUA, GSI) to SBU
- Complete **radiation hardness** study with neutron irradiation  $\Rightarrow$  **budget request** for procurement of samples
- Complete evaluation of **prototype lenses** in upgraded ODU laser setup
- Develop **prototype simulation**, define **beam test plan** and deliverables, identify required beam instrumentation
- Optimize **hpDIRC geometry** (bar size, pixel size, sensor coverage)
- Resume/continue hpDIRC simulation projects
  - “**ultimate DIRC**” and wide plate design options
  - hpDIRC with **reused BaBar DIRC bars**
  - hpDIRC  **$e/\pi$  separation** at low momentum

Outcome:  
\$75.2k

	100%	80%	60%
Postdoc, CUA, 50%	\$60k	\$60k	\$60k
Small-Pixel MCP-PMT Sensors	\$40k	\$20k	\$0
Prototype Evaluation (Travel, CUA)	\$15k	\$15k	\$15k
Prototype Equipment	\$5k	\$5k	\$2k
Radiation Hardness test	\$1k	\$1k	\$1k
Travel, CUA/GSI	\$9k	\$9k	\$6k
Total	\$130k	\$110k	\$84k



# BACKUP SLIDES

# eRD14 – EIC PID consortium

An integrated program for particle identification (PID)  
for a future Electron-Ion Collider (EIC) detector

A suite of detector systems covering the full angular- and momentum range required for an EIC detector

- Different technologies in different parts of the detector
- Focus on hadron ID with an electron ID capability

A cost-effective sensor and electronics solution

- Development and testing of photosensors (to satisfy EIC requirements)
- Development of readout electronics needed for prototyping

Consortium synergies (including reduction of overall R&D costs)

- Close collaboration within the consortium, with coordinated goals and timelines (e.g., DIRC & LAPPD, mRICH & dRICH, sensors and readout for prototype tests, etc).
- Strong synergies with non-EIC experiments and R&D programs (PANDA, CLAS12, GlueX, PHENIX, commercial LAPPDs) result in large savings.

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## An integrated program for particle identification (PID) for a future Electron-Ion Collider (EIC) detector

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